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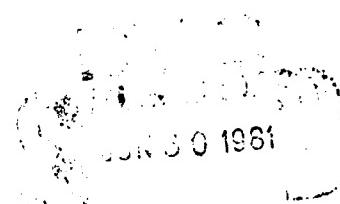
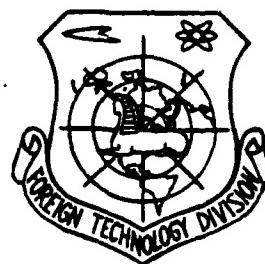
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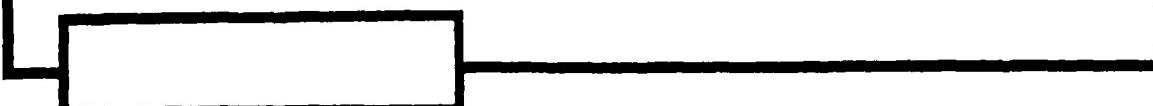


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## A 20 Years' Survey of Laser Science and Technology in China (I)

The correspondent, Ji Zhong; The reporter, Qun Li

### Abstract

The historical process and some achievements in the field of laser science and technology in China are presented briefly. First of all, an epitome is given to the readers, and then the entire development of the first ruby laser in our country is discussed. It is shown that various types of lasers were developed in competition during the 1960's, and laser application research emerged in the 1970's. Moreover, an urgent appeal for enhancing fundamental research was made. A typical laboratory is described. The opto-electronic industry attracts wide attention.

It has been 20 years since the first ruby laser was made.

The developments in the field of laser science and technology have been through the stage of primary basic research, technical preparation and are now reaching a stage of full development. From the international point of view, the milestone for full development is: the development of laser technology has not only been in depth, but also widespread; from far vacuum ultra-violet ( $1000 \text{ \AA}$ ) to far infra-red (400 microns), laser emissions for the entire electromagnetic wave spectrum have been generated. Breakthroughs have been achieved for some laser parameters which may represent the progress in laser technology. For example, the power for neodymium glass laser systems and  $\text{CO}_2$  lasers has been over  $10^{13}$  watts; the pulse width for ultra-short-duration pulsed lasers has been narrowed to  $10^{-13}$  sec; the frequency stability

for He-Ne laser has reached  $10^{-16}$ . Laser technology has become a powerful research tool and a new technical discipline. It has generated widespread applications and revived ancient optics to solve many problems which could not be solved with traditional technology. More noteworthy, its impact on every category of natural science is so tremendous it is difficult to be measured. We are convinced by the great achievements of laser technology in the last 20 years that lasers are one of the great inventions in this century.

Our country began laser developments very early. In September 1961, the first ruby laser was made successfully. Laser technology has been developed rapidly in our country since then. In order to concentrate our manpower, a laser research center was established in Shanghai in 1964. Since then, various laser technology research units have been organized. There are over 20 laser research institutes in our country to date. In the meantime, we have built many factories to produce laser instruments and other relative components, and materials. A competitive team of laser professionals is thereby organized.

The top priority for laser science and technology study is laser devices. China has successfully developed many types of laser devices. Basically, we have most of the existing types of laser devices. Currently, there are about 40 types of laser devices in use: For example, our neodymium glass laser system, continuous and high repeat frequency YAG laser, He-Ne laser, sealed CO<sub>2</sub> molecular laser, TEACO<sub>2</sub> molecular laser, optimum room temperature CO molecular laser, etc. have been close to or in the frontier of worldwide laser technology. The components and materials for those lasers have been systemized and commercialized to provide advantageous conditions for the development and applications of laser technology.

The applications of laser technology in China have their own characteristics.. We have extensively applied laser technology to microprocesses, hole drilling, welding, cutting, detection, calibration, precise measurements, etc. The outcomes are satisfactory. There are more than 40 types of laser devices used in industry. In particular, the medical applications of lasers in China are more impressive. More than 130 types of diseases have been cured by lasers in our country. We have accumulated a great clinical experience in this aspect which is rarely achieved by other countries. Moreover, the development of laser technology for eye diseases has been even more successful, particularly in iris surgery; our country apparently leads the world. The laser applications in basic research are also very important. There has been new progress on laser-controlled fusion, laser communications, laser separation of isotopes, etc. Obviously, laser technology has made great contributions to our socialism.

In order to enhance the development of laser technology, we must also emphasize academic exchange. In 20 years, we have held four national conferences on laser technology. In summary, the first conference approved several theoretical and experimental arguments and reviewed the conditions for the development of laser technology in our country; the 2nd conference reflected that various types of lasers were developed in competition; the 3rd conference was primary for collection and exchange of information and to form teams; the 4th conference was to enhance and upgrade our establishments. In order to accommodate the interest of the 1970's for laser applications in our country, many national and local laser workshops have been held in the past years. Table 1 lists a brief survey for several conferences. These conferences were significant in many aspects, so as to activate technical concepts, to promote technology exchange and to enhance the development of lasers in our country. In particular, many professional societies like "laser subdivision in applied optics

division" and laser societies in many provinces and cities were organized over the last two years. Laser science has become one of the eight top categories in our R & D policy. It has become one important branch in modern applied optics. Its importance has been recognized and will be more appreciated in the future.

Table 1. National Conferences, Meetings on Lasers

Conference Name	Date	Location	Number of members	Number of papers
Chinese Academy of Science 1st Conference on Photons	Jan.1962	Changchun	~ 40	~15
National 2nd Conference on Lasers	July 1963	Changchun	57	68
National 3rd Conference on Lasers	Dec.1964	Shanghai	140	103
National 4th Conference on Lasers	July 1978	Guangzhou (Canton)	260	250
Workshop on Gas Lasers	Nov.1973	Guangzhou (Canton)	140	46
National Conference on Low, Medium Power Solid State Lasers	Sept.1974	Changchun	220	70
Workshop on Crystal Growth	Oct.1974	Fuzhou(Foochow)	292	143
Symposium on Agricultural Applications of Lasers	Dec.1974	Foushan	103	26
National Conference of Semiconductor Lasers and Their Production	June 1975	Beijing	102	36

Conference Name	Date	Location	Number of members	Number of papers
National Symposium on Laser Power and Energy, Laser Measurement, and Development Plan	June 1975	Shanghai	93	15
National Conference on Laser Instrumentation and Processes	Nov. 1976	Liuzhou (Liuchou)	150	~100
National Conference on Medical Applications and Instrumentation of Lasers	June 1977	Wuhan	300	~100

#### AN EPITOME

The Shanghai Institute of Optical Instruments of the Chinese Academy of Science is one of the major establishments for laser technology R & D in our country. The establishment and development of the Institute has always been concerned and supported by our party and country. At a time when laser technology showed its viability and bright future, the National Science Committee and National Planning Committee, under the guidance of Premier Zhou Enlai, decided to found the Institute. In 1973, Premier Zhou appeared at the 10th Conference of the Chinese Communist Party. He was seriously ill at that time, but was still concerned with the development of laser technology. He met with comrade Gan Fushi about the state-of-the art and laser development and stated: "Lasers ought to be developed with applications". In more than ten years, the Institute has been continuously expanded and strengthened. Considerable progress has been made in laser technology in this Institute. The number of employees has been expanded from more than five hundred to over

fourteen hundred; the number of research laboratories has been increased from 7 to 14. A competitive technical team, including several distinguished laser experts and first generation laser professionals, was organized in the Institute. This is a young team with an average age of less than 40. It is also very active, and filled with innovative conceptions. Some of them built the first laser in our nation. Many of them are struggling at the frontier of laser technology. Most of them are newcomers. At the 1978 National Conference on Sciences, 16 items developed by the Institute and 13 items related to the Institute were awarded by the National Science Committee, Chinese Academy of Science and City of Shanghai. In regard to such distinguished achievements, we recall the words delivered by the long time director of the Institute, comrade Wang Dashin, on the day of commencement of the Institute: "A combination of two teams from Beijing and Changchun in Shanghai would make things perfect."

The long-term policy for the Shanghai Institute of Optical Instruments is to develop intense laser technology, to do research on various lasers, laser materials, components and other technologies, to look into the basic physical mechanisms of lasers, and to actively develop laser applications. All these will emphasize coordination.

As early as 1961, Jeng Simin at the Changchun Institute of Optical Instruments independently developed a concept of Q modulation. He proposed the idea to use a mechanical rotating mirror for Q modulation. Another team developed the first high power ruby laser in 1963. However, the team foresaw, based on their experiments, that further developments of ruby lasers would be hindered by the limitations of the dimensions and mass of ruby crystals. Therefore, by the end of 1964, they made the decision to use neodymium glass as the main stream laser material for future technological development. At the time, foreign countries were still not clear about prospects of the neodymium

laser. The decision made by the team in the Institute was decisively significant for the development of high-power laser technology in China. In the fall of 1965, the Institute successfully built the first four-level transverse wave amplified neodymium glass laser in our nation. In the meantime, they initiated theoretical and experimental investigations on laser-induced nuclear transmutation. In 1973, they built simultaneously two sets of high power neodymium glass laser systems with a power as high as  $10^{13}$  watts. They used the laser generated by the system to bombard frozen deuterium and LiD, and induce the nuclear transmutation for the first time with an output of nearly  $10^3$  neutrons/pulse. In the following year, they built a large, single-channel laser system with a piecewise large-diameter amplifier installed as the last stage. The output power was upgraded to  $2 \times 10^{14}$  watts and the pulse width was  $2 \times 10^{-9}$  sec. A target of deuterium polyethylene was irradiated by the laser of the system.  $2 \times 10^4$  neutrons/pulse were produced. Of course, the neutrons induced by such irradiation are not originated through the mechanism of nuclear fusion. In order to develop and study the

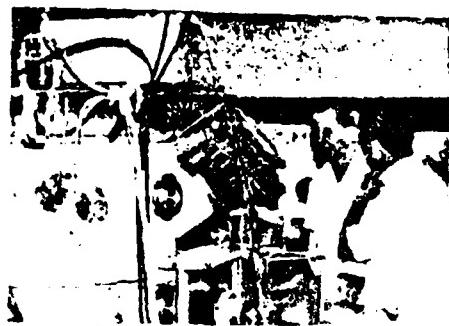


Figure. In July 1979, Vice Premier Fang Yi visited the Shanghai Institute of Optical Instruments, checked state-of-the art research on laser-induced nuclear transmutation.

laser-induced nuclear transmutation, the institutions built one set of six-channel high power laser systems in 1975. This set is currently the largest laser system in our nation. In the Spring of 1977, this system (total output power  $3 \times 10^{14}$  watts and pulse width  $10^{-9}$  sec) was used many times to irradiate (multi-beam) glass shell, and the initial compression effect in the laser-driven target was first observed. This indicated that the research on the laser-induced nuclear transmutation was upgraded to a level which would prove the principle of centripetal nuclear explosion step by step. Since 1978, they have advanced a great deal on basic research. The Institute has its own impressive technology and projects. For instance, the neodymium glass, Xenon lamp, laser thin film and other optical components used in their laser systems were manufactured by the Institute. In addition, they also solved some key technical problems such as those related to laser equi-ion detection, high precision focus target, plane and spherical transmutation target, etc. Among them, the high precision TV monitor, photoelectric focus adjustment technique for the large single channel and six channel vacuum target chambers were developed by them in 1973.

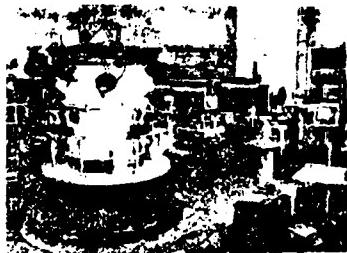


Figure 1. The vacuum target chamber for laser-induced nuclear transmutation, six-channel target installation, built in 1975.

At the time when the neodymium glass laser was developed, the transverse excitation, high pressure CO<sub>2</sub> high-power laser system was built. The system is composed of three major components in series: oscillation - contact amplifier stage, large-diameter ultraviolet preionization amplifier stage, and electron

beam controlled amplifier stage. We predict that the system will be applied to experimental investigations on laser heating for ionic crystals.

In summary, research on laser-induced nuclear transmutation has advanced after more than ten years of study. However, more breakthroughs can be achieved only if we are willing to pay the high price.

Besides research on high-power laser systems, the Institute also conducted research on various medium and low-power lasers. They can be classified in the following six categories:

. Neodymium glass laser; Primarily use silicate glass series including single pulsed generator, repeat pulsed generator and ultra-short pulsed generator, etc.

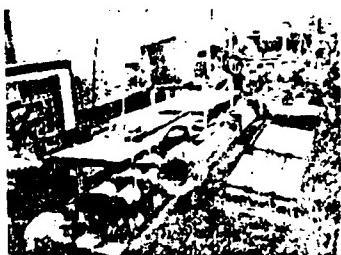


Figure 2. TEACO<sub>2</sub> high-power laser apparatus.

. Crystal laser; The crystals used for the laser include ruby, yttrium, aluminum, garnet, etc. There are various types of lasers made of garnets, such as nanosecond single pulsed, high repetitive pulsed, ultra-short pulsed, continuous, multi-frequency, modulating, etc.

. Gas laser: The gases used for lasers include helium-neon, CO<sub>2</sub>, CO, argon, nitrogen, neon, methylic fluorine, methyl alcohol vapor, copper, aluminum vapor, etc. The CO<sub>2</sub> laser is of different types including straight pipe, bending, enclosed cir-

culation, waveguide, etc.

. Semiconductor laser: The devices include GaAs single junction and heterojunction. The research efforts are also directed towards intense laser technology.

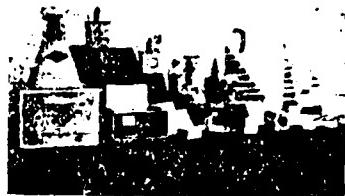
. Quasi-molecular laser: The operating systems which have already resulted in laser outputs include xenon fluoride, xenon chloride, xenon bromide, argon fluoride, etc.

. Dye laser: The dye most used is rhodamine 6G; pumping methods include xenon lamp, yttrium aluminum garnet laser, nitrogen laser, argon laser, etc.

Table 2 lists some typical lasers developed by the Institute along with brief descriptions from which we may understand that some of them lead in our nation, some of them fill the gap in our country, while some have caught up with international leadership.

Many necessary components, materials, technologies and elementary techniques have been developed or manufactured in the Shanghai Institute of Optical Instruments. Today, their base looks even better. The Institute has organized a more complete system of theoretical and technical research on glass lasers. There are more than ten glass lasers in mass production and for widespread applications. Their quality is excellent. In addition, the Institute also developed high quality ruby and yttrium aluminum garnet crystals. Recently, they successfully grew  $\pm 52$  mm x 45mm sapphires. As for laser components, their experience on high-energy pulsed xenon lamps, high-power pulsed xenon lamps, high-repetition pulsed xenon lamps, high-power continuous krypton lamps and short-duration pulsed xenon lamps are highly appreciated. In particular, the quality of the high-repetition pulsed xenon lamps and short-duration pulsed xenon lamps is not far from the

frontier in the world. Other components such as high-reflection films for various wavelengths, reduced reflection film, semi-transparent film, protection film for crystal surfaces, and interference fitting plates are of a compatible quality. The institute has demonstrated its excellence in optical design, photoelectronics, measurements of laser parameters, optical surveillance, precision instrumentation, etc.



Laser components, instruments and materials.

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Various xenon lamps used in pumping lasers.

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The Institute has actively prepared to export high-repetition YAG lasers, TEACO<sub>2</sub> lasers, waveguide CO<sub>2</sub> lasers, laser glass, pulsed xenon lamps, laser thin films, optical lenses, F - F calibrators, laser plane interferometers, etc.

Following the development of laser technology, basic research on lasers has been enhanced steadily. In several areas, the research has been very fruitful.

. The theoretical investigations have been very intense on the new structure for harmonic oscillation cavities, the modular theory of cavities, modular measurements, separation, modular limitations under high excitation, dynamic processes of lasers, the optimum operating conditions for lasers, modulation of laser beams, characteristics of laser transmission, etc.

. The research on laser nonlinear optics, such as multi-frequency and high-order harmonic waves, quadra-wave mixed frequency and frequency transformation, parametric oscillation and amplification, self-focusing effects, observation and elimination, etc., has made impressive progress.



Dr. Angnew of the American Atomic Energy Company visited the mixed frequency and frequency transformation laboratory in the Shanghai Institute of Optical Instruments.

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Professor Lin Shouji of the University of California visited the parametric oscillation and amplification laboratory at the Shanghai Institute of Optical Instruments.

15



Professor Schlosser of Cambridge University in England visited  
CARS spectrum Laboratory in Shanghai Institute of Optical  
Instruments.

/5



Professor Tong Zuonliang of Cornell University visited laser  
glass self-focusing laboratory at Shanghai Institute of  
Optical Instruments.

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Table 2. Several High- and Low-Power Lasers  
Developed in the Shanghai Institute of Optical Instruments

Order	Name of Instrument	Characteristics of Structure	Level of Quality	Published Report
1	YAG High-Repetition Laser	Crystal bar with liquid circulation cooling, two crystal bars connected, modulating Q by multi-reflection rotating mirror, water cooling, pulsed xenon lamp pumping	Output power $10^{-7}$ watts, pulse width $6 \times 10^{-9}$ sec, repetition rate $10^6$ cps, fiber-coupling $3 \times 10^{-7}$ cps, continuous operation, wavelength $1.06 \mu\text{m}$ , cumulative 10 $\times 10^6$ pulses, portable with leading products in the world	Early 1971. - 1972.
2	YAG Continuous High-Power Laser	Two bars connected, delimiting longitudinal surface, incorporated with optimum module (fixed problem).	Pump laser $10^{-6}$ W, 100 bursts, pulse width $10^{-8}$ sec, wavelength $1.06 \mu\text{m}$ , fiber-coupling, output power $10^{-3}$ W.	Early 1971. - 1972.
3	YAG Dye Locking Mode Laser	Half confocal cavity, single transverse mode operating with He-Ne laser dye locking mode	Output pulse width $10^{-7}$ sec, 20~30 micro-p.s., single pulse $10^{-10}$ J, 1000 pulses, output single pulse controllability $10^{-7}$ , time, frequency	Early 1973

Order	Name of Instrument	Characteristics of Structure	Level of Stability	Development Period
4	High-Power Multi-frequency Laser	One-level oscillation, one-level amplification, KDP multi-frequency.	Oscillations are all Gaussian, energy stability over 10%, lifetime in operation.	1969 - 1970
5	Three-state High-Power Multi-Frequency Laser	YAG oscillator plus three-level glass Nd amplifier, KDP, KD*P multi-frequency.	Stability parameters: efficiency > 10%, power conversion efficiency > 10%, lifetime > 100 hours, energy stability over 10%, lifetime > 100 hours, pulse rate > 10 Hz, incident in the system.	1970 - 1971
6	1.064 Glass Picosecond Laser	Composed of dye longitudinal mode oscillator, single pulsed selector, and four-level amplifier.	Output duration < 10 <sup>-10</sup> sec., beam diameter 100 microns, divergence angle 1 mrad, beam intensity > 10 <sup>13</sup> W/cm <sup>2</sup> , beam width 10 <sup>-10</sup> sec., resulting in 10 <sup>13</sup> J/cm <sup>2</sup> .	1971 - 1972

		5 picoseconds, peak power $10^3$ watts, inten- sity $10^{13}$ w/cm <sup>2</sup> , close to leadership in the world.
Solid Electron Controlled CO <sub>2</sub> laser	Solid anode electron gun, excitation volume 3 liters (length 1.7m) operation gas 1.0 atm.	The maximum laser energy 100 J/cm <sup>2</sup> , the maximum laser output density 100 Joules/liter, pulse width 1~3 $\mu$ sec., efficiency 11~12%, laser intensity close to leadership in the world.
Hot Electron Beam Controlled CO <sub>2</sub> laser	Hot cathode electron gun, excitation volume 3.7 liters, operation gas 1 atm.	The maximum laser energy 100 J/cm <sup>2</sup> , the maximum laser output density 100 Joules/liter, pulse width 5~10 $\mu$ sec., efficiency 11~12%, laser intensity close to leadership in the world.
Q-SI type three reflection CO <sub>2</sub> laser.	Formation of three water- cooled light sources by three CO <sub>2</sub> lasers oscillation, the wavelength 10.6 $\mu$ m, the maximum power 1000 watts each. The laser will be excited by CO <sub>2</sub> gas, incorporation in beam source for the entire machine, also equipped with a gas pump.	Controlling system Q-SI laser, 100 watts, maximum 1000 watts, maximum output power 1000 watts, maximum output energy 1000 Joules, maximum output intensity 100 Joules/liter, maximum output efficiency 12%.



13	$\text{CO}_2$ Branch Selection Laser	Adapting piezo-electric ceramics self-controlled feedback to control cavity length, light trapping coupling to select different output wavelengths, steel support, isolated cavity.	Can select 30 lines - April 1978 but in the range 4000-5000 nm. $\sim 100$ cm, cavity length $\sim$ 10 m, single branch TE10 mode, time stabilized or frequency operation below 100 $\sim$ 10 <sup>-7</sup> , power switch- ing at 100 Hz, 1000 W laser.
14	$\text{CO}_2$ Branch Selection Laser	Using light trapping from waveguide electrostatic excitation laser to select branch, discharge tube length 1.5m, inner diameter 3.12mm.	In August 1978, 100 nm, 10 <sup>-7</sup> power switchable, 100 Hz switching, 1000 W laser, 1000 W, 1000 W power switchable discharge tube length 1.5m, inner diameter 3.12mm branch selection using light trapping from waveguide electrostatic excitation laser.
15	Un-pumped laser selection branch laser	Accepting parallel plane waveguide light trapping discharge, operating under 1 nm, extensibility consideration.	Un-pumped laser selection branch laser, 100 nm, 10 <sup>-7</sup> power switchable, 100 Hz switching, 1000 W laser.
16	Ultraviolet Pre-pumped branch selection atmospheric laser	Using ultraviolet pre- pumped branch selection branch selection $\sim$ 100 nm, ultraviolet laser, atmosphere, intra-cavity structure.	Ultraviolet pre-pumped branch selection branch selection $\sim$ 100 nm, ultraviolet laser, atmosphere, intra- cavity structure, new technology, novel

		lengths of 1.03 microns is attained in the laser cavity, the stimulated emission rate is
17	Nd Laser Pulsing Dye Laser	lengths of Nd oscillating resonator, filter- driven & variable in the laser, Nd:YAG is and more than ten other types are used.
18	Q-Switched Pulsing Dye Laser	repetitive pulsed under Q-Switch, the driving Q-S, the driver, a
19	Q-Switched Dye Laser	lengths of 1.03 microns only, Nd:YAG, Nd:Glass, Nd:Glass, Nd:YAG, Nd: Glass, Nd:Glass

20	UZIPO, Mini Crystal Laser	Shallow mini crystal grown in the fluorite, semi- precious jewelry, xenon laser pumping the laser longitudinal pumping.	The UZIPO is a mini crystal with a diameter of 16 mm, cylindrical shape, transparent, light weight, low cost, durable and inexpensive crystal in our country.	May 1974 Nov. 1974
21	Copper Atom Vapor Laser	Refractive materials including copper bichloride and pure copper vapor, self-excavation and self- excitation with an harmonic oscillation. Blum- lein circuit, filling up to 100 torr.	Wavelength 320 nm, 100 mW 500 Hz, pulse width 100 ns, output power around 100 mW. Copper vapor is an ideal oscillator because it has a large absorption cross section.	May 1974 Aug. 1974
22	Light Pumping Far Infrared Laser	Using CO <sub>2</sub> laser as pumping source, organic molecule paper is operation mater- ial, steel support, room temperature water cooling.	Light pumping, 100 mW, 100 mW, wavelength 10.6 micron, pumping with CO <sub>2</sub> laser, the light source, the heat energy at the time, laser output with a wavelength of 10.6 micron, the output intensity, the intensity pumping with CO <sub>2</sub> laser, filling the gas in the cylinder.	June 1974

. Intense light radiation effect: they study effects of various parametric intense lasers on various transparent media, opaque media and metallic materials, including the mechanisms of degradation;

. Laser plasma physics: they study the mechanism of interaction between high-power lasers and plasma, investigate a physical model of centripetal nuclear explosions.

A professional institute like this one is closely related to the historical process of the development of laser technologies. It reflects an epitome of the development of laser business in our nation but not the whole story. Accordingly, a large number of technical professionals in the Institute actively participate in the national academic exchanges, including information exchanges, gathering others' experience so as to promote their own projects. Particularly over the past several years, international exchanges became very numerous. Since 1972, according to statistics, they have received over 90 teams of guests from 20 countries with a total of over 200 professionals. Among them are many well-known laser experts who have exchanged information with the staff of the Institute. Some of them even worked in the Institute on a short-term basis. Incidentally, the academic atmosphere of the Institute is even more viable.



In Sept. 1978 members of the Yugoslavian Academy of Science and Technology visited the Shanghai Institute of Optical Instruments.

/S



In June 1979 Members of Japanese Science and Technology Conference visited the Shanghai Institute of Optical Instruments.

/8



In Sept. 1979 Members of U.S. IEEE visited the Shanghai Institute of Optical Instruments.



In Sept. 1979 Chairman of the International Committee of Optics (ICO), Professor Roman of Neurenberg University, West Germany, visited the Shanghai Institute of Optical Instruments.



In June 1979 Professor Wang Jenping of University of California visited the Shanghai Institute of Optical Instruments.

## THE PAST AND THE FUTURE

Today, after 20 years of rapid development of laser technology, we reminisce about the birth of the first laser in our country - ruby laser. The reminiscence is very meaningful. The following photo shows the first ruby laser in our nation.



The first ruby laser apparatus in China.

In Changchun, a team of researchers led by a Chinese Optical expert, Wang Doxian, investigated various problems they were facing in the late 1950's. Those problems were concluded by them into a key question: Can we overcome several "impossible" forbidden areas as addressed in classical optics - the intensity of a light source can only decrease and not increase; the image can only become dimmer and not brighter; the wavelength can only be lengthened and not shortened, etc. At that time, comrade Gu Chiu-Wu proposed a new idea: place an atomic luminous body in a Fabry-Perot interferometer to lengthen the wave train of a certain frequency, and the monochromatic property is expected to be raised. At that time, the team, full of innovative ideas, read the article written by Schawlow and Townes on light excited emission. Then an investigation on the problem was initiated. Mei Mann's success expedited the progress made by the team. A young optical expert named Wang Zuziang submitted an experimental proposal which was written in accordance with our national conditions and a series of theoretical analyses and calculations. He then led the team to perform the first

laser experiment in China. Since the existing ruby crystal was only 30 mm in length and the conversion efficiency of laser pumping with a spiral xenon lamp was considered to be low, they adopted an upright tube xenon lamp accompanied by a spherical image coupling light focusing system. The first Chinese ruby laser was designed according to the idea. Parameters are listed in Table 3.

Table 3. Some Key Parameters of the First Ruby Laser in China

Component	Key Parameters
Ruby bar	Concentration of chromium ions: 0.04% length 30 mm, Ø 5 mm, One terminal entirely covered by a silver layer, the other terminal covered by a silver layer with transparency somewhere between 2 ~ 15%.
Upright, tube pulsed xenon lamp	Interval between electrodes 40 mm Inner diameter 8 mm
Focus cavity	Two reflective hemispheres, spherical radius 60 mm
Electric source	Capacitance 2660 $\mu$ F Voltage 350 550 V

The laser apparatus was first operated in July 1961. Luminescence was observed. Two months later, i.e., in Sept. 1961, the output was observed. A bright spot distinguished from the luminescence was observed several meters away. Thereafter, the photo-electron detector and oscilloscope were used to display the "peak" effect for the light signal and confirm a laser output. The output energy measured with a photoelectron detector was approximately 0.003 joules. The event was announced two months earlier than a similar experimental result announced by Russia. The

experience on this laser apparatus indicates our self-motivation to overcome various technical difficulties and our innovation in design ideas.

If we regard the birth of the first laser as only a beginning, then we may wonder how to evaluate its impact. We had better to cite a paragraph appearing in a report:

"Another example for the important goal of the development is the excited emission, particularly excited light emission. Monochromatic interference lightwaves in a very narrow wave packet can be achieved by excited light emission. The intensity will be far above the order of magnitude previously achieved. This will provide a new powerful tool for basic research, will open up a new territory for atomic and nuclear physics, and will also start entirely new research on optical chemistry and other intense light effects. This will become an important optics branch in the traditional optics. Excited light emission not only influences basic research, but also will enhance engineering techniques, calibration, exploration, tracking techniques for the long-range flight objects. In the meantime, it may develop into a new possibility for cosmic communication. Therefore, the growth and development of the excited emission techniques may initiate a widespread impact in the next ten years. A new high technology may develop."

The paragraph is cited from the Guidelines for the National Science Development in the years 1963 ~ 1972 (draft). The paragraph evaluated the importance of laser development. Its guidance is still significant today.

## THE COMPETITION FOR DEVELOPMENT

The establishment of the first Chinese ruby laser opened up the door for the development of laser technology in China. A variety of laser devices came about thereafter. Only a few major laser devices are introduced here. However they represent the characteristics of the development of laser technology in China in the 1960's. According to statistics, China has over 40 types of laser devices at the present time. Table 4 lists several major laser devices along with the dates when they were first successfully operated.

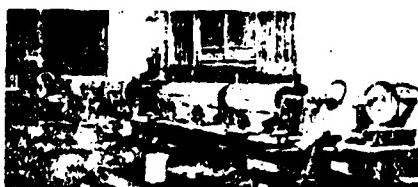
Table 4. Variety of laser devices and dates they were first operated

Name of Device	First Time Operated
Ruby laser	Sept. 1961
He-Ne laser	May 1963
Neodymium: glass laser	June 1963
CaF <sub>2</sub> : U <sup>3+</sup> laser	June 1963
GaAs P-N junction laser	Dec. 1963
CaWO <sub>3</sub> : Nd laser	1964
Pure Xe, He-Xe laser	1964
CaF <sub>2</sub> : Dy <sup>2+</sup> continuous infrared laser	1964
CO <sub>2</sub> molecular laser	1965
Argon ion laser	1965
Krypton ion laser	1965
HCl chemical laser	1965
Inorganic liquid laser	1967
YAG laser	1968
GaAs - GaAlAs heterojunction laser	1971
CO <sub>2</sub> TEA laser	1971
CO <sub>2</sub> gas laser	1972
DF, HF gas chemical laser	1973

N <sub>2</sub> laser	1973
Iodine laser	1974
Gas explosion gas laser	1974
Room temperature continuous operating, heterojunction GaAs laser	1975
Solid explosion gas laser	1975
Continuous tunable dye laser	1975
XeF quasi-molecular laser	1977
XeBr, XeCl quasi-molecular laser	1978
Electron beam pumping XeF quasi-molecular laser	1978
Nd PO <sub>5</sub> laser	1978
Room temperature CO molecular laser	1978
Room temperature branch CO molecular laser	1978
HCN far infrared laser	1978
16 $\mu$ CO <sub>2</sub> laser	1979
Li Nd PO <sub>4</sub> laser	1979

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The picture shown here is a high-energy neodymium: glass laser device. The first neodymium: glass laser was built by the Changchun Institute of Optical Instruments in May 1963. The glass material was fabricated there. At that time, Comrade Gan Fusi, based on his many years of experience in optical glass research, collected silicate material doped at the proper concentration. He finally fabricated a laser glass material which is the basis of the current neodymium laser system. To date, the output of high-power neodymium laser systems in China has reached  $2 \sim 3 \times 10^{11}$  Watts\*. In addition, a  $10^{12}$  Watt device is being built.



High-energy neodymium: glass laser device.

/10

He-Ne laser is the most popular laser device in China. It is a gas laser. According to statistics, there are about 80 units in China, which do research and production for He-Ne laser devices. Many of them have production lines. The national product of He-Ne laser tubes is around 15,000. The lifetime of the laser tubes is several thousand hours. The dimensions of a typical device are 240 mm and 300 mm. Some units employed low melting point glass sealing of new technique\*\* to prolong the lifetime of the device to  $10^4$  hours. An improvement over the structure of the laser tube reduces the arc discharge voltage to one third of that of a regular tube \*\*\*.

A He-Ne laser, stabilized with methane saturation absorption, will have a stability of over  $10^{-11}$  and a repetition of over  $4 \times 10^{-11}$  if the sampling time is in the range of 1~10 seconds. In some experiments, the stability and repetition could be over  $10^{-14}$ . A laser device stabilized by iodine absorption can have a stability in the range of  $(2\sim 3) \times 10^{-11}$  with a sampling time of 1 sec, and can have a stability of  $5 \times 10^{-11}$ , repetivity of  $2 \times 10^{-10}****$  with a sampling time of 10 sec.

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\* Laser-Induced Nuclear Transmutation Laboratory, the Shanghai Institute of Optical Instruments of Chinese Academy of Science: "Experimental Study on the Micro Spherical Target Irradiated by Six Laser Beams", <<Laser>>, 1978, 5, No. 5~6, 9.

\*\* "A Method to Seal a He-Ne Laser Tube with a Glass of Low Melting point", <<Laser>>, 1979, 6, No. 8, 50. "Sealing Techniques for the Optical Aperture and Laser Cavity with Low Melting-Point Glasses", <<Laser>>, 1979, 6, No. 9, 39.

\*\*\*\* "Study on the Characteristics of the He-Ne Laser Device Stabilized with Methane Saturation Absorption", <<Laser>>, 1978, 5, No. 5~6, 142.

\*\*\* See the article in "Laser, 1978, No. 5-6, p. 141.

It is only when we have access to the properties or characteristics of a He-Ne laser which has capabilities that have been raised above their normal levels, especially in the lifetime of the laser, that it becomes possible to bring the full capabilities of this laser to bear on actual operations. In China, from 1975 to 1979, there were seven technical conferences or symposia organized by specialists in the fields concerned to make a comparative examination of the capabilities of the He-Ne laser. At these conferences, technical discussions were held as well as discussions on how to attack the problem.

The first He-Ne laser was manufactured in May, 1963. This is a date which has already been entered into the record book of history of the development of lasers in our country. At that time, this type of apparatus could produce a power of 1 milliwatt, and the degree of diffusion or scattering in the laser beam was smaller than an arc angle of 0.00032. After two more years, the He-Ne laser had reached the point where it could be placed in formal production, was sold commercially, and could rapidly be developed.

Among gas lasers, the CO<sub>2</sub> laser is also in the role of a very generally used apparatus. The types which are available in our CO<sub>2</sub> lasers are quite numerous. The common type of CO<sub>2</sub> sealed lasers, which produce less than 500 watts of power, are now capable of producing 52 watts at a standard distance of 1 meter, and are capable of continuous point burning for more than 5,000 hours\*.

In 1965, when research on CO<sub>2</sub> lasers was just getting started, conditions for research were quite difficult. Even the CO<sub>2</sub> gas that was used in the experimentation was obtained by the laboratory personnel themselves, by adding heat to

$\text{CaCO}_3$ , and thus decomposing it. It was only after going through yet another series of experimental techniques that it was possible to obtain  $\text{CO}_2$  gas which was spectrographically pure. After this was done, later research proved that the degree of purity of the gas was not an important factor. However, the process of scientific research is always convoluted, and this tenacity can serve as an example for those who follow.

Research was begun on the gas flow  $\text{CO}_2$  laser in 1971. The instrument involved was a combustion type with a flow of 10 kg. It could produce a continuous power of 37,000 watts\*\*. With this type of laser,  $\text{H}_2 + \text{CO} + \text{O}_2 + \text{N}_2$  and  $\text{C}_2\text{H}_2 + \text{CO} + \text{O}_2 + \text{N}_2$  type gases were used in an explosive gas-type of laser. This type of equipment was capable of producing energy which reached 500 joules and the pulse length was

nearly 0.5 sec \*\*. The picture shown below is a pulsed gas-explosion type of laser device which employs explosive solid-state materials including RDX, 662 and 7201, all containing large amounts of nitrogen. The output laser has an energy of 8.6 joules, and a half pulse width in the range of  $10 \sim 40$  milliseconds.\*\*

Since 1972, the transverse-mobilization type device has been under development. The current transverse-mobilization device with closed circulation has an output power of nearly 2KW\*\*\*, which is equivalent to an average power ratio of 20 W per centimeter of discharge length.

In 1971, a transverse excitation high-pressure laser device was successfully built in China. The device is abbreviated as TEACO<sub>2</sub> laser. The characteristics of the laser are: maximum output energy 400 joules/liter-atm \*\*\*\*; the pulse width for the longitudinal mode TEACO<sub>2</sub> laser is a few nanoseconds.

Besides, China also successfully developed argon ion, krypton ion, metallic vapor, quasi-molecular lasers, etc. The progress made on those lasers is very impressive.

The semiconductor laser device was the one among many laser devices developed in China in the early stages. In December 1963, the Semiconductor Institute of the Chinese Academy of Science first built a semiconductor laser device. The operation material was a GaAs junction which was fabricated using the diffusion method. The rectangular dimensions are  $0.15 \times 0.2 \times 0.8$  mm<sup>3</sup>. The two reflection planes in the harmonic oscillation cavity are composed of GaAs junctions. The pulse originated from the laser electric source is a rectangle with pulse width of  $2 \mu$  sec. The operation temperature is 77°K. When input current is very small, the intensity of the laser is isotropic, with a broader spectral line (170 Å); while for higher currents, the



Pulsed gas-explosion laser device.

location of the wavelength for peak intensity moves to the short-wave position with a decreasing width of the spectral line. As the current exceeds 2600  $\text{A}/\text{cm}$ , the width of the spectral line will be reduced to less than 10  $\text{\AA}$ . The fine structure of the emission spectra can be observed thru a high-resolution grating spectrograph. The wavelength for the most intense coherent amplitude is in the neighborhood of 8400  $\text{\AA}$ , with a line width less than 0.5  $\text{\AA}$ .

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\* "The Effect of Electrode and Gas Components on the Lifetime and Other Parameters of  $\text{CO}_2$  Lasers", <<Commencement Conference of the Chinese Optical Association -- Digest of Abstracts>>, Nov. 18, 1979.

\*\* " $\text{CO}_2$  Gas Dynamic Laser", <<Laser>> 1978, 5, No. 5 6, 49.

\*\*\* "2 KW Continuous Output for a Transverse Flow  $\text{CO}_2$  Laser", <<Laser>> 1979, 6, No. 8, 63.

\*\*\*\* "Electron Beam Controlled Discharge  $\text{CO}_2$  Laser", <<Laser>> , 1978, 5, No. 5 6, 55.

Other semiconductor laser devices which have been made in China include single junction GaAs lasers, heterojunction GaAs lasers, YAG light pumping diodes, tunable PbSnTe semiconductor lasers, etc. The pictures shown below are a heterojunction semiconductor laser device and its experimental apparatus. The lifetime of this device operating continuously at room temperature is nearly 5000 hours\*.



Semiconductor laser and its experimental apparatus.

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\* "500 Hour Room-temperature Continuous Operation GaAs/GaAlAs Heterojunction Laser," <<Laser>>, 1979, 6, No. 7, 44.

Proposal For the Use of Electrodeless  
Discharges as Optical Pumping for an  
Atomic Iodine Laser Amplifier of TW Order

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Abstract

Pulsed electrodeless discharges used as laser pumping provide high peak power, high UV content, high optical coupling efficiency, long lifetime and good reproducibility. These unique features seem very promising for high power atomic iodine lasers. A TW order laser amplifier 20 cm in diameter and 8 m long pumped by this scheme is proposed. The characteristics of such a pumping system are discussed.

The promotion of the research on laser-induced transmutation enables the atomic iodine lasers to reach a level of  $10^3$  joules, 1 nanosecond for a single beam [1, 2]. Since the gaseous medium is employed, and the wavelength for the near infrared laser is close to  $1.3 \mu\text{m}$ , along with application of high-quality chemical components, the high-power iodine laser device has excellent optical qualities [3, 4]. The size of the focus spot is only 2.5 times the diffraction limit. The power density can be as high as  $10^{18} \text{ W/cm}^2$ . This is also crucial to intense light research.

Typically, an atomic iodine laser device is to generate iodine atoms in excited states by optical disassociation of  $\text{C}_3\text{F}_7\text{I}$ . The center of the absorption band is  $2730 \text{ \AA}$  with a bandwidth of  $310 \text{ \AA}$ . The quantum efficiency to generate infrared photons is near 1 [5]. The energy conversion efficiency in this ultraviolet absorption band for a short-duration pulsed flasher is 8%. The last stage amplifier for a high-power iodine laser is normally filled with  $\text{C}_3\text{F}_7\text{I}$  of less than 10 torr, along with other gas such as Ar,  $\text{SF}_6$ , etc. ( $\sim 1 \text{ atm}$ ). The excited atoms will decrease 10% after  $10 \mu \text{ sec}$ . For a nanosecond pulse, only  $7/12$  of total excited atoms are in the pool of laser transition. This is attributed to nuclear spin ( $I = 5/2$ ). Iodine is a storage-type medium. However, the output is limited to below  $10 \text{ joules/cm}^2$  due to nonlinear destruction of optical components. The last-stage amplifier is in general very long. A short-dutation pulsed flasher is used owing to a short life-time of excited states. For instance, the 64 xenon lamps of 5 torr [1], used in the Asterix III, has a pumping time of  $20 \mu \text{ sec}$ . The intra-cavity explosion lead used by the Russian Institute of Physics has a pumping time of  $50 \mu \text{ sec}$ . Since the pumping efficiency for the ultraviolet light is not so high, the efficiency for a high-power iodine laser is only 0.15%.

The coaxial-type pulsed electrodeless discharge light source is suitable for a medium used for a high-power, short-duration pulsed, ultraviolet excited laser. The experience gained by China [6] and the United States [8], and later Russia [9,10] indicate that the efficiency of the electric energy converted to discharge tube,  $n$ , can reach  $70 \sim 80\%$ . In the ultraviolet region, the luminous intensity of low-pressure argon is higher than that of xenon. The double pulses have been used before, i.e., after a pre-ionization discharge, the total luminous intensity has been increased an order of magnitude [11].

The bright temperature for an electrodeless discharged plasma is in the range of 15,000 - 25,000°K, resistivity  $\sim 0.02 \Omega \cdot \text{cm}$ . These characteristics accommodate atomic iodine laser devices. We believe that the electric-light conversion efficiency for an electrodeless discharge tube, similar to the electrode discharge, is dependent on the average discharge power density. In order to examine the energy conversion efficiency, S. I. Andreev, et al. derived a formula for the effective resistance,  $R_{\text{eff}}$ , [10] in a discharge effective return circuit (Fig. 1), with a power density in the range of  $0.05 \sim 1.7 \times 10^9 \text{ W/cm}^3$ .

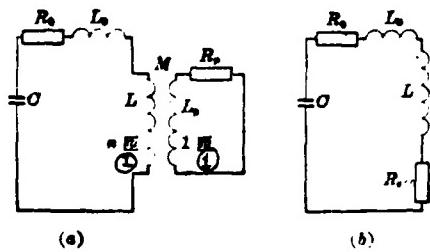


Figure 1. Electrodeless discharge return circuit (a) and effective return circuit (b).  $L_{\text{total}} = L + L_o$ ;  $R_{\text{total}} = R_{\text{eff}} + R_o$ ;  $T = 2\pi f \sqrt{L_{\text{total}} C}$   
Key: 1. winding

$$R_{\text{eff}} = 1.07 \times 10^{-3} \left( \frac{n^3 \Delta D^4}{l^2} \right) \\ \times f^2 \left( \frac{U}{L_{\text{total}}} \right) \\ \times \frac{1}{\left[ 1 + 3 \times 10^{-4} \left( \frac{n \Delta D^2}{l} f \frac{U}{L_{\text{total}}} \right)^2 \right]}$$

where  $n$  is the number of the initial stage coil windings,  $\Delta$  is the thickness of axial discharge tube (cm),  $D$  is the diameter of discharge tube (cm),  $l$  is the length of coil (cm);  $f$  is the frequency of the discharge return circuit (G Hertz),  $U$  is the

charging voltage of the capacitor C (volt),  $L_{\text{total}}$  is the total inductance for the return circuit (nH). We notice that the major portion in  $L_{\text{total}}$  is the inductance L of the initial-stage coil, which is

$$L = \frac{\mu_0 \pi D^2 n^2}{4l}$$

where  $\mu_0$  is the magnetic permeability in vacuum. L is in inverse proportion with l. This is advantageous to a long device, because the impedance decreases with increasing length and, with a single discharge tube, a short-duration pumping is for sure. Suppose that the supply energy,  $CU^2/2l$ , for a unit length is invariant; then  $1/f = 2\pi \sqrt{L_{\text{total}} C} \propto$  constant. In order to match pulse width, a change of winding number, n, is possible: when D is very large, we let  $n < 1$ . A compact single layer solenoid is available today in which n is only determined by the spiral angle.

For the purpose of comparison, an example is taken with dimensions similar to those in Asterix III. Let  $n=1$  (single reel),  $D = 30$  cm,  $l = 800$  cm, diameter of laser tube  $D_2 = 20$  cm,  $\Delta = 2$  cm, then  $L = 10$  nH. Take  $C = 320 \mu\text{F}$ ,  $U = 50$  KV, total energy 400 KJ, which is larger than that of Asterix III. Assuming the additional inductance in the return circuit,  $L_0 \ll 4$  nH, then  $R_{\text{eff}} = 3.6 \times 10^{-4} \Omega$ ,  $T = 1/f = 12 \mu\text{sec}$ . The resistance for a coil of single winding  $R = 7 \times 10^{-5} \Omega$ , and the resistance for an initial-stage return circuit is assumed to be  $R_0 \ll 1.8 \times 10^{-4} \Omega$ . The conditions required for  $L_0$  and  $R_0$  should be satisfied as possible in the return circuit design. The energy conversion efficiency for the discharge tube is then

$$\eta = R_{\text{eff}} / (R_{\text{eff}} + R_0) \sim 67\%$$

The power decay time for the return circuit will be

$$\tau = (L + L_0) / (R_{eff} + R_0) \sim 30 \mu \text{ sec}$$

The power density in the discharge tube is

$$w = (CU^2/2) \times \eta / \tau (\pi D \cdot l)$$
$$\sim 0.13 \text{ W/cm}^3$$

$\omega$  is not too high because of high volume. If we let  $\eta_{eight}$  represent the coupling efficiency to focus light and  $\eta_{spectrum}$  represent spectral matching efficiency, then the laser energy which could be stored in the cavity will be

$$E = (CU^2/2)\eta(7/12)\eta_{eight}$$
$$\times \eta_{spectrum}(\lambda_{absorption}/\lambda_{laser})$$

The last factor is due to Stokes loss, i.e., the ratio of wavelengths for absorption light and emitted light. Coaxial pumping  $\eta_{eight} > 0.8$  and  $\eta_{spectrum}$  is estimated similar to that for a flasher (0.08), then  $E \sim 3.6$  joules. If a portion of the energy can be induced in a nanosecond, the laser power can reach a TW order.

The ring voltage in the discharge tube  $E_0 \approx U \pi D \sim 550 \text{ V/cm}$ , which can discharge at a few torr. In order to stabilize the operation and enhance the light output, a pre-ionization pulse may be added. If necessary, a Crowbar switch may be employed to short circuit at a maximum initial stage current. Thus the repeat charging for the capacitor can be avoided.

Since the laser is induced by a transition of magnetic coupling poles, a non-uniform magnetic field caused by discharge and coil current will reduce the gain. This, however, benefits the amplifier because the parasitic oscillation may be depressed. Only when the current passes thru 0 is it equivalent to a Q switching. Besides, the excited waves induced by light pumping may destroy the uniformity of the medium. But the excited waves are centripetal, with a velocity of  $3-5 \text{ mm}/10 \mu \text{ sec}$  [1], so that a perturbation, with  $D = 30 \text{ cm}$  and  $\tau = 30\mu \text{ sec}$ , will be limited to the surface only. The larger the D, the more benefit we can get.

The structure of an electrodeless discharge tube is simple, and its illumination is uniform. If a laser tube can also be used as an inner wall of the discharge tube, a quartz tube can be saved. The operating lifetime for a flasher at high voltage, short-duration pulsed condition is  $10^3$  times. However, the lifetime for an electrodeless discharge tube is longer. For example, no significant change is observed after  $6 \times 10^4$  times of discharges [13]. The electrodeless discharge requires high voltage, low inductance capacitance, low impedance transmission, etc. But for short-duration pulses, electrode discharge requires these conditions to be satisfied also. The difference is that electrodeless discharge requires many switches in parallel, while electrode discharge requires many lamps in parallel. The electrodeless discharge pumping seems very promising for the applications in the laser-induced transmutation in the future if the spectral compositions can be improved so that the efficiency can be increased too. As a matter of fact, the above proposal can be tested through small experiments immediately.

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